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Digital image enhancement for recording rupestrian engravings: applications to an alpine rockshelter

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ABSTRACT

Image processing software, such as the DStretch plug-in for ImageJ or Photoshop, are currently used to make faint rupestrian pictographs more legible. During the ongoing study of an Alpine rockshelter, these software proved to be equally useful for the visualization of linear engravings and scratchings. This unexpected function of DStretch, created for the study of rupestrian paintings, made it possible to clarify and correct the previous recordings of an incised Iron Age warrior and to facilitate the digital tracing of a modern maritime scene. Even if such convincing results are determined by particular local geological conditions in this case, this function could facilitate the study of engravings in other contexts where the lithology of smooth rock surfaces produces a sharp contrast with incised images.

Image processing software are now commonly used to help the study of rupestrian paintings. Among them, Photoshop® (Domingo Sanz and López-Montalvo, 2002; McNiven et al., 2004; Mark and Billo, 2006; Brady, 2006, 2007) and DStretch® (Harman, 2005; Mark and Billo, 2006; Le Quellec et al., 2013) are the most widespread. The DStretch® plug-in for ImageJ© was designed by Jon Harman in 2005 in order to facilitate the visualization of faint rupestrian paintings which are difficult to see with the naked eye (Harman, 2005; Mark and Billo, 2006). This program uses the so-called decorrelation stretch algorithm to enhance digital images of pictographs. The contrast in the photographs is intensified and presented with false and artificial colors. This software is now currently used throughout the world to study rock paintings (Bahn, 2010), to help to complete previous inventories with images which had previously gone unnoticed and to improve the understanding of superimpositions without any direct contact with the rock surface and the pigments. There is no reason why such computer tools, based on color contrast, could not also contribute to a better record of rupestrian engravings when the contrast with the rock surface is sufficiently marked. I thus applied Photoshop® and Dstretch® to Alpine rupestrian images, for which it revealed unexpected and promising possibilities. Frequently used, and even created in the case of DStretch®, for the enhancement of paintings, these software appear to be equally efficient for highlighting linear incisions, in addition to faint pictographs. They could appear also very effective for the production of bidimensional records of linear engravings. The example chosen to illustrate this point is the ongoing study of the *Oullas rock shelter* (Saint-Paul-sur-Ubaye, Alpes-de-Haute-Provence, France).

1. A key site in the alpine environment

The site is located 2390 m a.s.l., in the Saint-Paul-sur-Ubaye district (Fig. 1). The south–east facing rock surface bears an exceptional range of linear incisions, pecked engravings and painted figurations, from the Neolithic period onwards (Fig. 2). Among the more ancient images, there is one of the eight examples of Alpine Neolithic paintings, composed of five possible plant patterns. These paintings were then covered with pecked engravings of "Remedello-type" daggers, which provide evidence of the use of this rock surface as an ideological medium between 2900 – 2400 BC and which also supply the only one clear *terminus ante quem* for such schematic pictographs (De Marinis, 1994). The "Remedello-type" daggers are known in the necropolis in the Pô plain and these images are characteristic of the steles and rocky outcrops of the Central Alps, and of the steles in the Adige Basin and the province of Sion/Aoste. Remains of these daggers appear on a very damaged part of the panel implying that other images, which have now disappeared, also adorned this rock surface. The corpus of images also includes Iron Age incisions, patronymic initials, a painted and decorated signature

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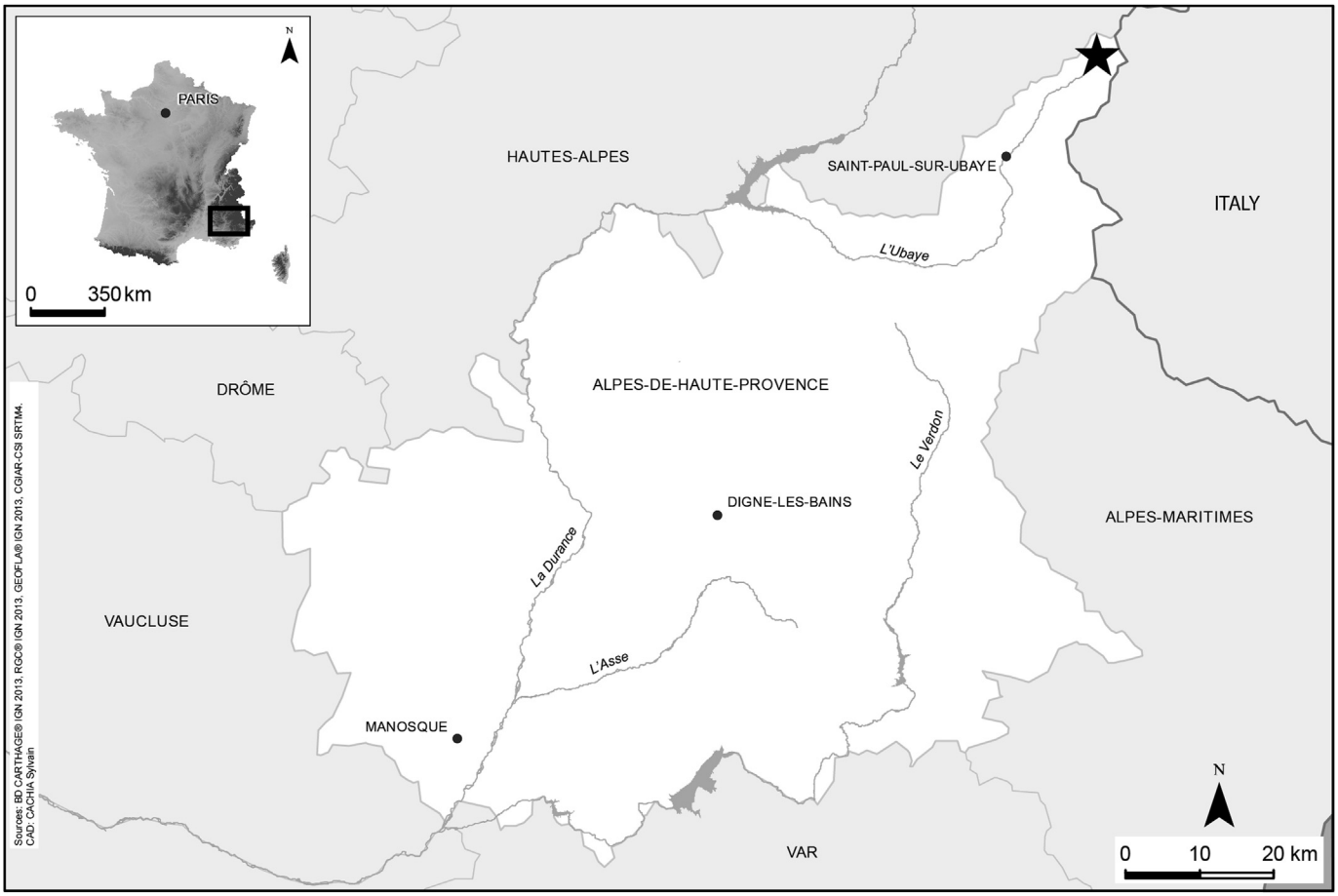

Fig. 1. Situation map of the Oullas rockshelter.

dated to 1568, a maritime scene attributed from the structure of the ship to a period between the 16th and the 20th centuries (P. Poveda, personal communication), dates and animals, spread over a panel with a height of 0.80–1.20 m and a length of 7 m. The Oullas rockshelter is consequently of the utmost importance for the understanding of the Neolithic period in the Alpine arc and, more broadly, for the understanding of human mobility in high mountains and the evolution of the engagement of societies with high altitude zones from prehistoric times. Every effort should be made to record and understand this rock shelter and its images.

Fig. 2. The south–east facing painted and engraved rock surface and the modern pastoral structure (Photograph: C. Defrasne).

Several partial or partially published studies have been conducted by various researchers on this rock surface since the time of its discovery in the eighties (Arcà, 2004; Hameau, 2010; Müller and Jorda, 2014; Müller et al., 2004; Trustram-Eve). In 2006, the site was excavated and revealed levels dated to the Middle Age (before the 11th century, 11th–13th centuries) and to the Modern era. Previous levels cannot be reached because of the presence of a rock chaos (Mocci and Walsh, 2007).

Significant differences can be noted between the various tracings of rupestrian images from the Oullas rockshelter from previous studies. I focus here particularly on the Iron Age images. Indeed, Müller and Jorda (2004, p. 99) described an Iron Age duel scene composed of two warriors facing each other (Fig. 3A). In 2004, A. Arcà suggested another interpretation, describing the body of the second warrior as the shield of the first one (Arcà, 2004) (Fig. 3B). N. Trustram-Eve's observations were similar (Trustram-Eve). More recently, P. Hameau recognized, in the same images, two painted warriors engaged in a duel scene (Hameau, 2010, p. 88–89). Therefore, previous studies present disparities as regards both the technique and the nature of these Iron Age images.

The ongoing study, which began in 2010, aims to complete the analysis of this crucial site in the western Alps and to produce accurate tracings using computer techniques. It is only with such methods that it will be possible to solve the interpretative problems related to some of these rupestrian images and to achieve more objective tracings. The first step of this programmed study required the use of DStretch®, which had never been applied – up until now – to Alpine rupestrian images (Defrasne and Bailly, in press). Consequently, a complete photographic coverage of the rock surface with natural and artificial light was completed with a Canon EOS 350D (8 megapixel) camera with 28 mm and 50 mm Canon lenses in order to carry out image analysis.

2. The archaeological background of digital enhancement of rock art images

Before divulging the unexpected application of DStretch® and the equivalent result obtained with Photoshop® during the study of the Alpine rockshelter, it is important to recount briefly the role of digital image enhancement in an archaeological/rock art context (more details could be found in Brady and Gunn, 2012). The use of digital image enhancement was due to the desire to develop non-invasive methods of rock art recording in order to preserve this fragile heritage as much as possible. Methods of enhancement have been recognized as an important tool in rock art recording since the early 1980s but its use to improve the clarity of rupestrian images dates back to the end of 1990s and the emergence of affordable software such as Photoshop® (Brady, 2006, 2007; Brady and Gunn, 2012; Buchner et al., 2000; Domingo Sanz and López-Montalvo, 2002; Mark and Billo, 2002; McNiven et al., 2004).

The use of DStretch®, created in 2005, is much more recent (Acevado and Franco, 2012; Brady and Gunn, 2012; Domingo et al., 2013; Harman, 2005; Mark and Billo, 2006; Quesada Martínez, 2010) and became a vital step in the methodology of rock art recording (Brady and Gunn, 2012, p. 628; Le Quellec et al., 2013), fulfilling different objectives (identification of new images or new details (Acevado and Franco, 2012, p. 169; Domingo et al., 2013, p. 1880; Guttiérrez Calvache et al., 2009), correction of previous recordings, study of superimpositions (Brady and Gunn, 2012), understanding and construction of chronological sequences (Gunn et al., 2010)). As mentioned in the introduction, image processing software are now commonly used in rock art studies, particularly in Africa, Australia and America. The use of such techniques is less systematic for the study of European contexts (Colella, 2013; Domingo et al., 2013). But, all these examples are dealing with pigment images. To my knowledge, digital image enhancement applied to an engraved rock surface is still very rare (Cassen et al., 2014a,b).

3. Digital image enhancement and the reading of linear engravings

When applied to the rock surface of the Oullas rockshelter, DSretch® corrected and completed the tracings of Neolithic paintings and brought to light some previously overlooked images. Indeed, DStretch® revealed the red painted signature inscribed "*J. Volaire 1568*" (Fig. 4), mentioned above. This signature was only partly recorded during previous tracings since it is largely invisible to the naked eye (Arcà, 2004; Müller and Jorda, 2014; Müller et al., 2004) and cannot be recovered with a Photoshop® enhancement

Fig. 3. Direct tracings of the Iron Age warrior by Müller et al. (A) (Müller et al., 2004) and Arcà (B) (Arcà, 2004).

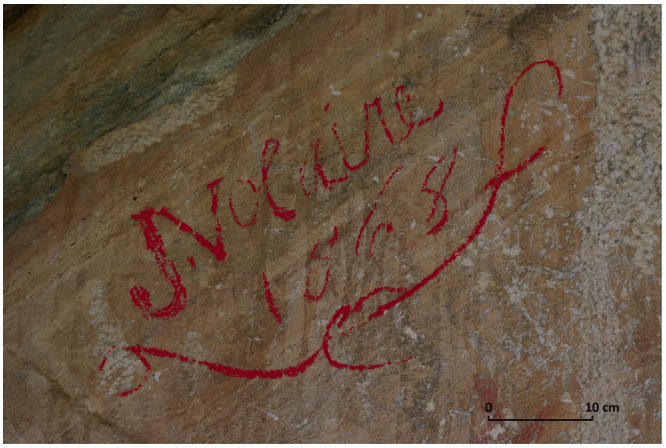

Fig. 4. Recording of the signature dating back to the 16th century. The signature has been extracted with Photoshop®, by means of the selection of same color pixels, from the DStretch® enhancement produced with the built-in YDS matrix. (Photograph: M. Bailly, image processing: C. Defrasne).

(Le Quellec et al., 2013). As far as paintings are concerned, DStretch® appeared much more effective than Photoshop® to highlight faint details.

But DStretch® proved to be of much more assistance than expected. Indeed, during this work, a new application of the software appeared, namely the DStretch® capacity to show up linear engravings. The term incision is used here to denote a "*shallow rock marking produced with a single application of a pointed tool, consisting of a narrow smooth groove*" (Bednarik, 2010). It also refers to what A. Leroi-Gourhan called the *percussion directe posée* and the *percussion indirecte posée* (Leroi-Gourhan, 1943). On this Alpine rock surface, DStretch® has improved the visualization of such linear incisions and scratchings. And yet, the creator of the plug-in himself wrote in one of his articles that he achieved better results on pictograph images than on engravings (Harman, 2005). Two examples will be addressed here to underline this capacity of the software. The first is the Iron Age warrior which has been subject to miscellaneous interpretations by previous researchers. The second is an aquatic scene depicting a boat, which is interesting, given the high mountain context.

Firstly, for the image of the warrior, the built-in YBK matrix helped to clarify the outlines (Fig. 5). The reds were selectively suppressed so that the dark colors (here the scratching) were brought out. The final result corrects and completes the previous interpretation and tracings (Fig. 6B). One warrior is engraved, confirming A. Arcà's and E. Trustram Eve interpretations. But image enhancement with DStretch® allows us to define some elements of the warrior which remain invisible without computer tools since the rock surface is damaged and the engraving is situated at a height of three meters, making manual tracing conditions difficult. On Arcà's tracing, parts of the chest and the spear, the right leg and the head of the warrior are omitted or do not appear entirely. These parts of the figure have been recovered using DStretch® enhancement.

For the study of the maritime scene, YBK enhancement appeared to be the best one. The complex combination of tracings forming the sail and its framework is thus more legible on the enhanced image than on the original one (Fig. 7). But the final record (Fig. 8) is in this case not very different from that published by Müller and Jorda (Müller et al., 2004). However, such a result confirms the effectiveness of DStretch® for the study of rupestrian engravings.

For these engravings, and unlike Neolithic paintings, the results obtained with Photoshop® enhancement were in agreement with the document obtained with DStretch®. For the warrior, the contrast of the original image has been increased to highlight incisions whose pixels of the same color have been then automatically selected and replaced by an artificial hue (Fig. 9). The Iron age warrior is consequently clearly legible.

4. Convincing results due to specific conditions?

These results of digital image enhancement of linear engravings are essentially due to the specific conditions of the geological context. The lustrous schists of the Piedmont zone dominate the geology of the upper part of the Ubaye Valley. Consequently, the outcrops in this geographical sector are reddish. More specifically, the effectiveness of the software is improved on the *daggers rock* by the contrast of the engravings on the orange-colored patina of this very smooth schistose rock surface. Thus, the Oullas shelter combines two characteristics (contrast of the incisions on the patina and a very smooth rock surface) that facilitate the image processing. However, such a combination of features can also be found in other regions and it thus seems that this function of DStretch® and Photoshop® deserves to be more widely used and developed in the future. Moreover, although these geological conditions make the

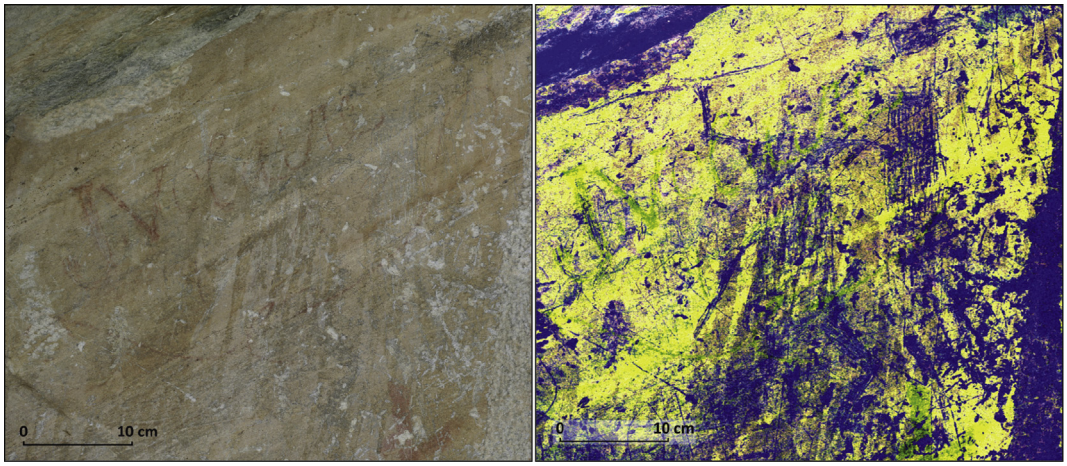

Fig. 5. The Iron Age warrior before (left) and after (right) the DStretch®-built-in YBK enhancement. Reds are removed and dark colors (incisions) highlighted. (Photograph: M. Bailly, image processing: C. Defrasne).

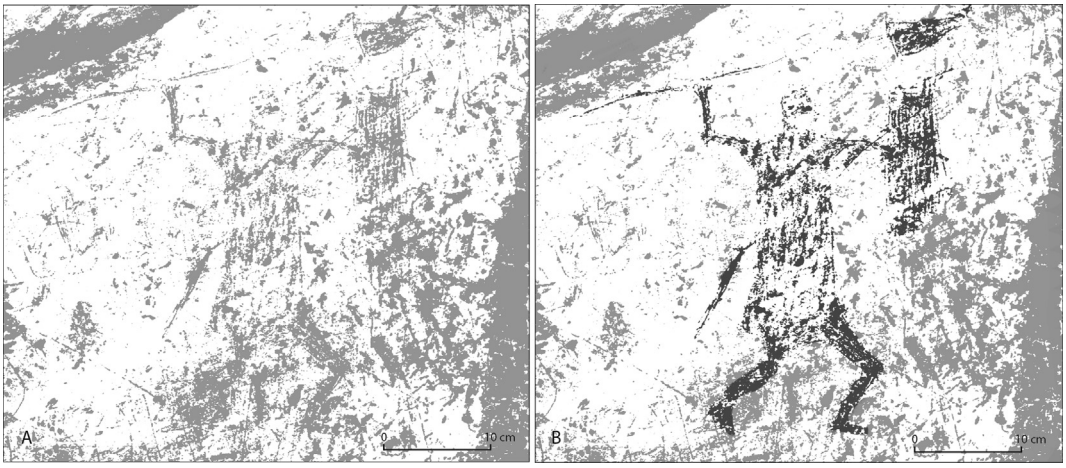

Fig. 6. Recording of the Iron Age warrior from the image processing with DStretch® (Recording : C. Defrasne). Incisions are extracted with Photoshop® from the enhanced image by means of the selection of same color pixels (6A). The final record (6B) highlights pixels understood as belonging to the initial warrior.

application of digital image enhancement easier, they are not necessarily the only ones conducive to the identification of engravings with such software. Examples of the enhancement of engravings with DStretch® are still exceptional but prove that the plug-in could be applied to images on other types of rock surfaces. For example, it helped to reveal faint peck-marks on orthostat R11 at Gavrinis (Britanny, France) (Cassen et al., 2014).

The DStretch® plug-in is currently regularly used for the study of paintings, but to our knowledge has never been used to record images engraved on rocky outcrops. However, this is only possible in certain conditions due to the fact that the software is based on color contrast. Therefore, this application confers on DStretch® an additional functionality for which it was not created.

5. Contribution of digital image enhancement to the study of the Oullas rockshelter

The contribution of digital image enhancement to the study of the Oullas rupestrian images is twofold. Firstly, from a methodological point of view, it provides more accurate and more objective tracings than preceding methods. Secondly, the correction of previous records strengthens the chrono-cultural context of the site.

The enhancement applied to the Iron Age warrior and the maritime scene makes the recording of the engravings much easier. The final digital recording of the first one was produced with Photoshop® from DStretch® images. The contrasted result obtained allows for the extraction of the color of the scratchings, which means that the warrior doesn't have to be redrawn (Fig. 6A). Such a method minimizes as much as possible the subjectivity of the final record. Indeed, digital image enhancement helps to obtain a more comprehensive understanding of a rupestrian image or a rock surface (Brady and Gunn, 2012) and provides precise and more complete work documents. But the image enhanced isn't the final tracing. The latter always results from the choices made by the analyst to display an explicit replica of the rupestrian image. On the final tracing displayed in Fig. 6B, the incisions understood as belonging to the warrior are presented in dark gray but other

Fig. 7. The maritime scene before (left) and after (right) the DStretch®-YBK enhancement. (Photograph: M. Bailly, image processing: C. Defrasne).

Fig. 8. Recording of the maritime scene. The lines constituting the structure of the ship have been redrawn with a graphic tablet from the DStretch® enhancement. Their width is only made up of a few pixels on the digital image making the extraction of the color of the engravings impossible. Shaded areas are not preserved anymore (Recording : C. Defrasne).

scratchings, the "background noise", present on the rock surface are preserved, presented in light gray, so that each reader can judge for himself the choices I made. The warrior isn't redrawn, as could be a manual tracing, but its final shape derives from the selection of pixels that I considered as being part of the original image. Although digital image enhancement reduces the degree of subjectivity, the latter is inherent in a bi-dimensional record (Brady and Gunn, 2012) as soon as the perception and the judgment of the analyst are required.

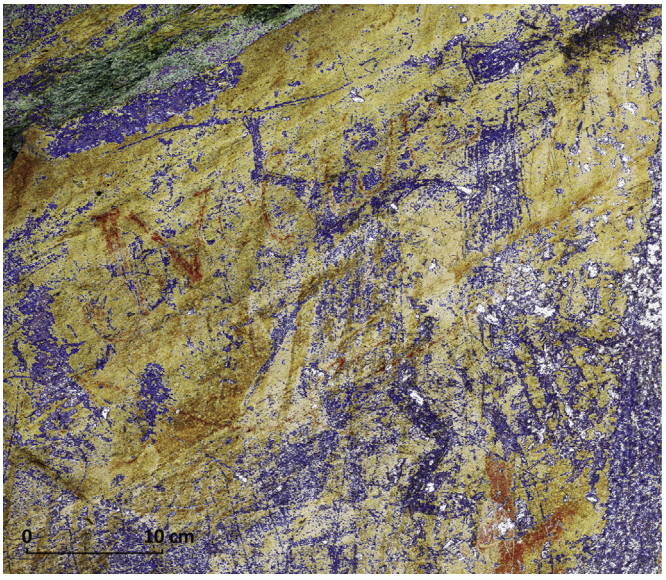

Fig. 9. Image processing of the Iron Age warrior with Photoshop®. The image contrast has been increased to highlight incisions whose pixels of the same color have been then automatically selected and replaced by an artificial hue (Photograph: M. Bailly, image processing: C. Defrasne). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

As regards the maritime scene and the fact that it is not composed of scratchings but of fine linear tracings, the width of which is only made up of a few pixels on the digital image, the extraction of the color of the engravings from the enhanced image was impossible. Moreover, there is not enough contrast between the incisions and the rock surface. Consequently, engravings are formed by pixels of different colors and it is impossible to produce a final tracing by selection of the color. The boat and the engraved figure were consequently redrawn from the DStretch® image with the vectorial graphic creation Illustrator® software.

The morphological characteristics of the Iron Age warrior and the maritime scene, were refined with the aid of digital image enhancement, thereby strengthening the chrono-cultural insertion of the images and, broadly, of the site, by assigning each of them to a particular "cultural sphere" in the broad sense of the term. The warrior is very similar to those engraved on the rock surfaces of Valcamonica in the central Alps and attributed, according to superimpositions and the associated engraved material culture, to the Iron Age and more precisely to phase IV2 ie between the half of the VIIth century and the end of VIth century (Fossati, 1991, 2011). As for the boat, its complex structure indicates that it is a sea boat and suggests that it can be correlated to ships characteristic of the region situated between the Ligurian coast and the Gulf of Lion. Its chronological attribution still remains to be defined, but it can be ascribed to the period spanning the 16th – 20th centuries (P. Poveda, personal communication).

Consequently, it appears that the Oullas rockshelter was, at least from the end of the Neolithic period to the Iron Age, integrated in a north italic cultural sphere, which is also reflected in the material culture from the close prehistoric copper mine of Saint-Véran (Barge, 2006). Italic influences could also have persisted until more recent periods, as evidenced by the structure of the ship. This chrono-cultural insertion of the site is essential in order to understand the nature and evolution of human mobility in mountain environments and cultural connections over long distances.

6. The application of DStretch® and Photoshop® for engravings enhancement and as recording techniques

Firstly, I would compare DStretch® and Photoshop®. As I previously mentioned, Photoshop® appeared much less effective than DStretch® for Neolithic and modern paintings enhancement. Regarding incisions, both software produced equivalent results. However, final recordings were made from DStretch® enhancement. This plug-in was preferred here due to the limited intervention required to obtain the same result. It's not a question of ease. But with DStretch®, the influence of personal intervention and subjectivity on the result is limited. Moreover, with regards to the advantages of DStretch® over Photoshop®, I could also add the financial aspect, as DStretch® is free software.

As for all new technologies or tools available for the study of particular kinds of archaeological remains, it is necessary to question the contribution of digital image enhancement software to the scientific environment and to describe the characteristics which distinguish it from other tools.

Other methods and techniques yielding very precise data acquisition have been developed and tested. For example, the method which consists in the synthesis of different views of the engravings taken with opposite oblique lights, allows for the identification of engraved images that cannot be seen with the naked eye (Cassen and Robin, 2010). Such a method, also used for recording linear engravings (Robin, 2010), is necessary to reveal all the light contrast on the edge of the carvings (Cassen and Robin, 2010, p. 4), generally when they are wide and deep.

Moreover, the study of pecked and linear engravings has benefited, in recent years, from the development of techniques aimed at producing accurate records of rock surfaces. Among them, photogrammetry and 3D laser scanning are widely used by scholars (Cassen et al., 2006; Ortiz Sanz et al., 2010; Plets et al., 2012; Simpson et al., 2004). Both of them provide precise three-dimensional models of engraved surfaces which allow for the extensive study of the engraved images in their rock context. The use of the 3D laser scanner to record fine linear engravings is currently used in Paleolithic contexts (Azéma et al., 2010; Mélard, 2010) on mobile objects or cave walls to decipher engravings, their technological aspects and wear (Mélard, 2010). But for some rock surfaces, particularly granular ones like granite, the precision of lasergrammetry does not exceed that of the photographic protocols mentioned above and both techniques are consequently complementary (Cassen et al., 2012, p. 13). Thus, DStretch® and Photoshop® also have to be considered as essential tools for the study of engravings, whether they are pecked or incised, and are complementary to other techniques like oblique light, laser scanning and photogrammetry (Cassen et al., 2014a,b).

In this paper, the aim of digital image enhancement was to identify and clarify faint incisions in order to produce an accurate bidimensional recording without any contact whatsoever with the rock surface. I am conscious that such two dimensional recording results in a loss of information, as the rocky reliefs and the interaction of images with relief is suppressed, but this is an essential step in the study of rupestrian images to focus on shapes, proportions, superimpositions and to compare the recorded images to other corpora and place them in a chrono-cultural context. Therefore, in order to produce a tracing of linear engravings to answer these questions, DStretch® and Photoshop® appear effective and sufficient. I would like to underline here the fact that tools must be chosen according to the questions raised. In the case of the Oullas rockshelter, the first step of the study requires a bidimensional record in order to establish the corpus of images painted or engraved on the panel and place them in their cultural context.

I should finally mention that photogrammetry (Chandler et al., 2007; Bryan and Chandler, 2008) and 3D laser scanning (Azéma et al., 2010; Domingo et al., 2013; Maumont, 2010; Simpson et al., 2004) require specialized abilities and, for the latter, specialized and onerous equipment which is difficult to carry to remote fieldwork locations, such as high mountain sites. Using digital image enhancement software in the field can help to avoid such difficulties and produce results on site. This latter aspect is essential since it allows for the immediate correction and improvement, if necessary, of the digital images of the rock surface.

On the Oullas rock surface, it is probable that RTI (Reflectance Transformation Imaging) (Díaz-Guardamino, 2012; Earl et al., 2011; Nieves and Tumi, 2012) or microphotogrammetry will provide more important details and a more accurate record of the linear engravings making up the Iron Age warrior and the maritime scene. These techniques, which reveal details of the surface which cannot be seen otherwise, could undoubtedly assist in the transcription of the eroded or damaged parts of the Oullas panel, such as one of the legs of the warrior. Indeed, enhancement software like DStretch® or Photoshop® do not distinguish the incisions from other surface alterations, and they both appear in blue on the enhanced images. Consequently, it is difficult to produce an accurate tracing of some parts of the images, like one of the legs of the warrior, caught up in an imbroglio of scratchings and abrasion of the rock surface. I am tempted to think that using these complementary techniques will allow us to bypass some of the difficulties still faced by DStretch® and Photoshop®.

7. Conclusion

Studies of engraved iconography tend to rule out image processing software, considered useful only when pigments are preserved. But the study of the Oullas rockshelter revealed that recording of incised images is greatly facilitated by digital image enhancement, bringing out an unexpected function of DStretch®. There is more; on this alpine rock surface, digital image enhancement with Photoshop® appeared much more efficient for engravings than for paintings. Consequently, and depending research objectives, digital image enhancement has now to be considered as an essential step of methods of engraved imagery recording. Nevertheless, where the rock surface is damaged, such techniques have limitations since they cannot distinguish between incisions and alterations. In these cases, they have to be relieved by others techniques which are not based on color contrast but on relief recording.

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